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INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference TS 6352 PCT	**FOR FURTHER ACTION** See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/EP 03/50996	International filing date *(day/month/year)* 12.12.2003	Priority date *(day/month/year)* 12.12.2002
International Patent Classification (IPC) or both national classification and IPC E21B4/00		
Applicant SHELL INTERN. RESEARCH MAATSCHAPPIJ B.V. et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 6 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 6 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the opinion
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
   - VI ☐ Certain documents cited
   - VII ☐ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand 30.06.2004	Date of completion of this report 09.03.2005
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized Officer Ott, S Telephone No. +49 89 2399-7429

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:

Description, Pages

1-15, 19	as originally filed
16-18	received on 28.01.2005 with letter of 27.01.2005

Claims, Numbers

1-7	received on 28.01.2005 with letter of 27.01.2005

Drawings, Sheets

1/2-2/2	as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   - ☐ the description, pages:
   - ☐ the claims, Nos.:
   - ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)).

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	4, 6,7
	No:	Claims	1-3, 5
Inventive step (IS)	Yes:	Claims	6,7
	No:	Claims	1-5
Industrial applicability (IA)	Yes:	Claims	1-7
	No:	Claims	

2. Citations and explanations

   see separate sheet

POINT V

1. The following documents are referred to in this communication; the numbering will be adhered to in the rest of the procedure:

   D1: US-5074681
   D2: WO0046478

2. D1 discloses a bore hole tool assembly comprising a housing (6) and a mandrel (12) reaching along an axial direction into the housing and a bearing system (22) for transferring an axial load between the housing and the mandrel and allowing rotation of the housing relative to and about the mandrel, wherein the bearing system comprises at least two bearing stages (fig.2) each arranged to transfer part of the axial load, whereby each bearing stage comprises bearing means (168, 170, 172, 174, 176, 178) and mitigation means (180, 182, 184, 186, 188, 190) for distributing the load substantially proportionally over the respective bearing stages (col.4, l.37-43), wherein the mitigation means comprises (fig.3) deformable means (228, 230, 236, 238) having a mechanical stiffness (col.4, l.35-37, col.5, l.5-7), arranged to transfer at least part of the axial load in series with the respective bearing means (col.4, l.29-35), wherein the mechanical stiffness of the deformable means (228) in at least one of the bearing stages (between 200 and 204) is different in magnitude from that of the deformable means (236) in the other bearing stage (between 202 and 206) or at least one other of the bearing stages.
   The subject-matter of claim 1 does not meet the requirements of novelty in the sense of Art. 33(2) PCT.

3. D1 also discloses a bearing system (22), for use in a bore hole tool assembly, for transferring an axial load between a housing (6) and a mandrel (12) reaching along the axial direction into the housing, and allowing rotation of the housing relative to and about the mandrel, which bearing system comprises at least two bearing stages (fig.2) each arranged to transfer part of the axial load, whereby each bearing stage comprises bearing means (168, 170, 172, 174, 176, 178) and mitigation means (180, 182, 184, 186, 188, 190) for distributing the load substantially proportionally over the respective bearing stages (col.4, l.37-43), wherein the mitigation means comprises

(fig.3) deformable means (228, 230, 236, 238) having a mechanical stiffness (col.4, l.35-37, col.5, l.5-7), arranged to transfer at least part of the axial load in series with the respective bearing means (col.4, l.29-35), wherein the mechanical stiffness of the deformable means (228) in at least one of the bearing stages (between 200 and 204) is different in magnitude from that of the deformable means (236) in the other bearing stage (between 202 and 206) or at least one other of the bearing stages.
The subject-matter of claim 5 does therefore not meet the requirements of novelty in the sense of Art. 33(2) PCT.

4. D1 discloses a method of designing a bore hole tool assembly in accordance with any one of claims 1 to 4, comprising the step of selecting a first bearing stage stiffness value for one bearing stage (implicitly).
The subject-matter of claim 8 differs from the disclosure of D1 in that the method comprises the further step of calculating, for given stiffness values of the parts of the housing that stretch between the bearing stages and given stiffness values of the parts of the mandrel that stretch between the bearing stages, the value for the second bearing stage stiffness whereby the axial load is distributed substantially proportionally over the respective bearing stages, thereby using the first bearing stage stiffness value as input.
The objective problem is therefore to provide a method for selecting constructional elements of the bore hole tool in order to achieve a determined distribution of the axial load over the respective bearing stages.
The solution of including the stiffness values of the housing, the mandrel and a bearing stage for calculating the stiffness value of a further bearing stage is not disclosed nor suggested by any of the available prior art, which relies on empirical methods to select the constructional elements.
The subject-matter of claim 6 does therefore meet the requirements of novelty, inventive step and industrial applicability in the sense of Art. 33 PCT.

5. D1 also discloses the subject-matter of claims 2, 3 as following shows:
- 2 : col.3, l.49-61.
- 3 : though not explicitly disclosed, the stiffnesses of the housing and the mandrel are likely to be very close, see dimensions in fig.2.

The subject-matter of claim 2, 3 does not meet the requirements of novelty in the sense of Art. 33(2) PCT.

6. The subject-matter of claim 4 does not meet the requirements of inventive step in the sense of Art. 33(3) PCT in view of document D2, which discloses a housing 5, a mandrel 600, the mandrel being a tubular end (fig.1).

7. The subject-matter of claim 7 meets the requirements of novelty, inventive step and industrial applicability in the sense of Art.33 PCT, as being dependent on a claim the subject-matter of which meets said requirements.

8. Following deficiencies are pointed out:
   - Rule 5.1a)ii) PCT: background art D1 and D2 not mentioned.
   - Rule 6.3b)I) and ii) PCT: incorrect two part form of independent claims with regard to D1, D2 respectively.
   - Rule 6.2 b) PCT in combination with PCT GL 3 III-4.11: no reference numbers.

sectional areas, of the mandrel and the housing. The mandrel and the housing are made of steel, with an elasticity modulus of $E_m = E_h = 2.1\times10^5$ N/mm^2. The outer diameter of the housing is restricted to a maximum of 181 mm. The inner diameter of a cylindrical mandrel is restricted to a minimum of 63.5 mm.

The bearings that are used are thrust bearings have an inner (shaft) diameter of 110 mm, outer (housing) diameter of 145 mm and axial length of 25 mm. The stiffness of all the bearings, as obtained from the bearing manufacturer, is $K_{bearing} = 4.11\times10^6$ N/mm, defined as the ratio of the axial force applied to the bearing and the axial shortening of the bearing resulting from the axial force applied to the bearing. The mandrel outer diameter along the sections of the mandrel is 100 mm such that the bearings can be fit and centred in the tool. The housing inner diameter along the sections of the housing is 150 mm. The section lengths (L_1, L_2, L_3, etc.) along the housing and mandrel required for the bearings, spring and fixtures/fittings to the mandrel and housing is 75 mm.

In order to be able to transfer a load of 500 kN, per bearing stage a disc spring is provided having a thickness of 20 mm and a stiffness $K_{spring} = 1.35\times10^6$ N/mm.

The stiffness K_h of each 75-mm section along the housing is given by:

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$$K_h = \frac{E_h A_h}{L}$$

$$= \frac{2.1\times10^5 \times \frac{\pi}{4}\left(181^2 - 150^2\right)}{75} = 22.6\times10^6 \text{ N/mm.}$$

The stiffness K_m of each 75-mm sections along the mandrel is given by:

$$K_m = \frac{E_m A_m}{L}$$

$$= \frac{2.1\times10^5 \times \frac{\pi}{4}\left(100^2 - 63.5^2\right)}{75} = 13.1\times10^6 \text{ N/mm}$$

At the first bearing stage two disc springs are mounted in series, which more practically halves the stiffness. The combined stiffness K_1 of the two springs and bearing in series at the first bearing stage is given by:

$$K_1 = \frac{\frac{1}{2}S_{spring} \times S_{bearing}}{\frac{1}{2}S_{spring} + S_{bearing}}$$

$$= \frac{\frac{1}{2}\times1.35\times10^6 \times 4.11\times10^6}{\frac{1}{2}\times1.35\times10^6 + 4.11\times10^6} \approx 0.58\times10^6 \text{ N/mm}$$

So that the relevant stiffness ratios K_1/K_h and K_1/K_m become:

$$\frac{K_1}{K_h} = \frac{0.58\times10^6}{22.6\times10^6} = 0.025,$$

$$\frac{K_1}{K_m} = \frac{0.58\times10^6}{13.1\times10^6} = 0.044$$

Using these values, the stiffness ratios for the other bearing stages can be calculated for which the load is divided proportionally over all the bearing stages:

$$\frac{K_2}{K_1} = \left[1 + 2\frac{K_1}{K_h} - 6\frac{K_1}{K_m}\right]^{-1} = \left[1 + 2\times0.025 - 6\times0.044\right]^{-1} = 1.27 \quad \Rightarrow \quad K_2 = 1.27K_1$$

$$\frac{K_3}{K_1} = \left[1 + 6\frac{K_1}{K_h} - 10\frac{K_1}{K_m}\right]^{-1} = \left[1 + 6\times0.025 - 10\times0.044\right]^{-1} = 1.16 \quad \Rightarrow \quad K_3 = 1.16K_1$$

$$\frac{K_4}{K_1} = \left[1 + 12\frac{K_1}{K_h} - 12\frac{K_1}{K_m}\right]^{-1} = \left[1 + 12\times0.025 - 12\times0.044\right]^{-1} = 1.29 \quad \Rightarrow \quad K_4 = 1.29K_1$$

These higher values for the bearing stage stiffnesses can be achieved by mounting stiffer springs in series with the bearings than at stage 1. The relation for the combined stiffness K_k at a bearing stage k (with two springs in series) can be reformulated as follows:

$$K_k = \frac{\frac{1}{2}K_{spring,k} \times K_{bearing}}{\frac{1}{2}K_{spring,k} + K_{bearing}} \quad \Rightarrow \quad K_{spring,k} = 2\frac{K_{bearing} \times K_k}{K_{bearing} - K_k}$$

Now the required spring stiffness values for the bearing stages 2, 3, 4 are:

$$K_{spring,1}=2\frac{K_{bearing}\times1.27K_1}{K_{bearing}-1.27K_1}=2\frac{4.11\times1.27\times0.58}{4.11-1.27\times0.58}\times10^6=1.796\times10^6\text{ N/mm}$$

$$K_{spring,2}=2\frac{K_{bearing}\times1.16K_1}{K_{bearing}-1.16K_1}=2\frac{4.11\times1.16\times0.58}{4.11-1.16\times0.58}\times10^6=1.608\times10^6\text{ N/mm}$$

$$K_{spring,3}=2\frac{K_{bearing}\times1.29K_1}{K_{bearing}-1.29K_1}=2\frac{4.11\times1.29\times0.58}{4.11-1.29\times0.58}\times10^6=1.830\times10^6\text{ N/mm}$$

In this practical example the differences in optimal stiffness values are relatively small. This is due the fact that by design the cross sectional areas of the mandrel and of the housing only differ a factor of about 2, which is favourable. In addition, by taking two springs in series at the first bearing stage, the values of the important ratios K_1/K_m and K_1/K_h could be restricted. With other design choices, the differences in optimal spring stiffness values could have become significantly larger.

Although for some applications, such as described above, the mandrel is preferably provided in the form of a tubular element, the invention also works for a solid mandrel, and even for housing and/or mandrel having a non-circular cross section such as a square cross section.

It is remarked that a bearing system as described herein can, in addition to its use in a bore hole tool assembly, advantageously be used in other fields of technology wherein relatively high axial loads are desired to be rotatably transferred from a housing to a mandrel or an axis, or vice versa. Examples of such fields include automotive applications, in particular heavy trucks, locomotives, drive shaft for marine vessels. This is also the case mutatis mutandis for the described method of designing the bore hole tool assembly.

CLAIMS

1. Bore hole tool assembly comprising a housing and a mandrel reaching along an axial direction into the housing and a bearing system for transferring an axial load between the housing and the mandrel and allowing rotation of the housing relative to and about the mandrel, wherein the bearing system comprises at least two bearing stages each arranged to transfer part of the axial load, whereby each bearing stage comprises bearing means and mitigation means for distributing the load substantially proportionally over the respective bearing stages, wherein the mitigation means comprises deformable means having a mechanical stiffness, arranged to transfer at least part of the axial load in series with the respective bearing means, wherein the mechanical stiffness of the deformable means in at least one of the bearing stages is different in magnitude from that of the deformable means in the other bearing stage or at least one other of the bearing stages.

2. Bore hole tool assembly according to claim 1, wherein the mechanical stiffness of the deformation means in at least one of the bearing stages is lower than that of the housing and that of the mandrel in a section bridged by that bearing stage.

3. Bore hole tool assembly according to any one of the previous claims, wherein the mechanical stiffness of the part of the housing that stretches between the bearing stages and the mechanical stiffness of the part of the mandrel that stretches between the bearing stages differ from each other by less than a factor of 3.

4. Bore hole tool assembly according to any one of the previous claims, wherein the mandrel is a tubular end, and preferably the housing is a tubular end.

5. A bearing system, for use in a bore hole tool assembly, for transferring an axial load between a housing and a mandrel reaching along the axial direction into the housing, and allowing rotation of the housing relative to and about the mandrel, which bearing system comprises at least two bearing stages each arranged to transfer part of the axial load, whereby each bearing stage comprises bearing means and mitigation means for distributing the load substantially proportionally over the respective bearing stages, wherein the mitigation means comprises deformable means having a mechanical stiffness, arranged to transfer at least part of the axial load in series with the respective bearing means, wherein the mechanical stiffness of the deformable means in at least one of the bearing stages is different in magnitude from that of the deformable means in the other bearing stage or at least one other of the bearing stages.

6. Method of designing a bore hole tool assembly in accordance with any one of claims 1 to 4, comprising the steps of:

a) selecting a first bearing stage stiffness value for one bearing stage;

b) calculating, for given stiffness values of the parts of the housing that stretch between the bearing stages and given stiffness values of the parts of the mandrel that stretch between the bearing stages, the value for the second bearing stage stiffness whereby the axial load is distributed substantially proportionally over the

respective bearing stages, thereby using the first bearing stage stiffness value as input.

7. Method according to claim 6, wherein step b. comprises:

b1) determining a first stiffness ratio being the quotient of said first bearing stage stiffness and the stiffness of the housing;

b2) determining a second stiffness ratio being the quotient of said first bearing stage stiffness and the stiffness of the mandrel.